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REQUIREMENTS FOR AUXILIARY STIFFENERS ATTACHED TO PANELS UNDER COMBINED COMPRESSION AND SHEAR

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SUMMARY

Panels of aluminum alloy sheets, framed by side and end stiffeners, were subjected to combined loading by means of offset knife edges applying loads to top and bottom end plates with reacting forces against the end plates supplied by laterally acting rollers.

The test specimens were 17S-T aluminum alloy sheets 0.040 inch thick in panels of 10-inch width and three different lengths (approximately 10, 20, and 30 in.). Data were obtained for the bowing of transverse and longitudinal ribs of rectangular cross section and varying depths mounted on one side of the sheet only, for several ratios of compression to shear loads. Limiting values of the moments of inertia were calculated from these measurements. The experimental values exceed the theoretical values given by Timoshenko for the case of simply supported sheets with uniformly distributed boundary stresses.

The work reported includes measurements of the effective shear moduli of the nine test panels with and without ribs. These data are compared with values published by Lahde and Wagner.

INTRODUCTION

Economical use of material in structural panels stiffened by ribs requires some means of determining the necessary flexural rigidity of the ribs. Methods for calculating the required moments of inertia of stiffening ribs have been outlined by Timoshenko (reference 1) for cases of rectangular sheets stiffened by transverse or longitudinal ribs and loaded in shear or compression. The moments of inertia so calculated are those for which the ribs remain straight when the plate buckles under load.

There is evidence that in practical cases the required rigidity of ribs on sheet panels is greater than that predicted by the approximation theory based on equating the sum of the strain energy of the buckled plate and that of the ribs to the work done by the external forces. It is therefore desirable to have experimentally determined limiting values of γ for the required moments of inertia.

Data were obtained on the bowing of ribs of different moments of inertia under panel loads gradually increased to nearly the yield values (as determined from preliminary tests) on each of nine types of rectangular sheet panels stiffened by transverse or longitudinal ribs of rectangular cross section, mounted on only one side of the sheet.

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SYMBOLS

Test specimens are identified by a code number (for example, 11T2) in which the first digit specifies the length-to-width ratio, the second the number of ribs, and the last the reciprocal of the rib depth in inches. The letters T and L are used to indicate ribs in the transverse and longitudinal position, respectively. The following summarized notation is substantially that used by Timoshenko.

A cross-sectional area of rib

a panel length, between screw lines

a' width of rib cross section (3/8 in.)

$B = EI$

b panel width, between screw lines

b' depth of rib cross section

b_L limiting value of b'

c 2c = depth of rectangular beam (equation (3))

c,c' sheet diagonals (fig. 5)

dc increase of panel diagonal c

−dc' decrease of other panel diagonal c'

$$D = \frac{E\ h^3}{12(1 - \mu^2)}$$

E modulus of elasticity (10.3×10^6 lb/in.^{2} for 17S-T aluminum alloy)

e base of Naperian logarithms

G_e effective shear modulus

h thickness of sheet

I moment of inertia of rib cross section relative to axis through a' edge

K knife edge

k knife-edge displacement, inches

l longitudinal distance between gage points (fig. 5)

l length of beam between supports (equation (3))

L longitudinal stiffener

P knife-edge load, pounds

S slope of δ against P curve

S_o slope of δ against P curve at zero rib thickness

T transverse stiffener

w lateral distance between gage points (fig. 5)

$\beta = \frac{a}{b}$

δ deflection of rib at midpoint

$\Delta = \frac{A}{bh}$

γ shear stress

$\gamma^{*} = \dfrac{B}{bD}$, panel in compression $= \dfrac{12\,E_{st}\,I_{st}(1-\mu^2)}{b\,E_{sh}\,h^3}$

$\gamma = \dfrac{B}{aD}$, panel in shear (See reference 1, chap. VII.)

γ_L limiting value of γ for stiffener of large rigidity

ϵ mean compressive strain

λ A constant

τ shear stress in sheet, $\dfrac{\text{shear load}}{hb}$

μ Poisson's ratio (0.33 for 17S-T aluminum alloy)

APPARATUS, MATERIALS, AND TEST PROCEDURE

The method used to subject the specimens to combined compression and shear is shown schematically in figure 1. The load was applied to the test panel through two knife edges K and the small rollers r; while reactions occurred through rollers R, eight in number located in pairs at the four corners of the panel. With the knife edges in central positions, the panel was subjected to a compressive load. When the knife edges were displaced laterally, the panel experienced a load of combined compression and shear. When the knife edges were over the vertical line of screws in the side stiffeners, it was assumed that the loading was pure shear.

The frame of the testing jig was built from structural steel (figs. 2 and 3). The vertical guides for the test panels were angle irons (5 by 5 by 1 in.) bolted in pairs to form T's in which slots were machined to receive the panels. Rigidity of the frame was secured by welding four plates (20 by 8 by 1 in.) between the vertical members at the top and bottom. The frame rested on a base made from an H-beam (10 by 10 in., weighing 72 lb/ft) between the flanges of which vertical stiffeners cut from angle iron (4 by 4 by 1/2 in.) were welded below each of the upright members of the frame to provide a rigid support for them.

Loads were applied by a hydraulic jack of 7-ton capacity (Blackhawk Mfg. Co. Model C-11-G), mounted on an upright H-beam bolted to one side of the frame. The jack was provided with a pressure gage (Marshalltown Mfg. Co.) of 6-inch diameter calibrated to read loads from 0 to 20,000 pounds for a 1.544-inch-diameter ram. The lever bar was a piece of No. 2 Samson steel (6 by 1 by 60 in., The Carpenter Steel Co.). The roller bearing used for the fulcrum of the lever was of $4\frac{1}{2}$-inch diameter and 1-inch length (generously supplied by Messinger Bearings, Inc.). Knife edges were machined from Stentor steel and hardened; while the rollers were cut from drill rod and were hardened.

The end plates shown in figures 3 and 4 were machined from tool steel and had a rectangular cross section with a height of $1\frac{7}{8}$ inches. Rollers R of 3/8-inch diameter were recessed in the end plates to bear against the upright guides of the testing jig.

The panels tested were of 18-gage 17S-T aluminum alloy of commercial grade made by the Aluminum Company of America, cut so that the direction of rolling was along the (vertical) direction of loading in the jig. The stiffening ribs and the side stiffeners were milled from 17S-T bar stock. Side stiffeners were cut to butt cleanly against the end plates. The fit of the panel in the slot of the vertical steel guides was within 0.005 inch, but the specimen could be pushed along the guides by hand. A list of sheet dimensions and sketches of the nine types of panel tested are shown in table I and in figure 5.

The bowing of the stiffening ribs was measured by dial gages (Federal Products Corp. Model D-8-IS, full jeweled) mounted as shown in figure 2, connected to the ribs by means of 30-gage aluminum wire. Dial gages also were used to obtain data on the effective shear modulus. For this purpose they were mounted along the diagonals of the sheet panels as shown in figures 2, 3, and 5, connections being made with 26-gage aluminum wire.

PRECISION

The validity of these measurements depends on three factors: correct calibration of the gages used to measure loads and deformations, a rigid frame of reference for the deformation measurements, and negligible friction between sheet panel and guides and in the loading system.

Dial gages were checked against a Gaertner comparator. Those of the full jeweled type were found to give reproducible readings under the conditions of use when the aluminum wire was directed along the axis of the gage. The calibration of the jack gage was checked against a Crosby dead-weight gage tester and a correction curve drawn. Load measurements are judged to be accurate within 50 pounds and deformation measurements within 0.003 inch.

A satisfactory check was made of the rigidity of the jig by substituting for the aluminum test panel a steel plate of 7/16-inch thickness and applying the maximum load to be used in the tests.

RESULTS AND ANALYSIS

Limiting Values of Gamma

Data of bowing against knife-edge load were obtained for several depths of stiffening ribs and for positions of the knife edges ranging from pure compression to practically pure shear. When plotted, the data of bowing (δ) against load (P) resulted in smooth curves with fairly well defined slopes. Curves obtained from a sequence of five different knife-edge positions show a regular decrease in slope with decreasing values of the ratio of shear to compression. The range of values of the slope is much less for sheets with longitudinal ribs than for those with transverse ribs. These characteristics are shown by the sample curves of figures 6 and 7, for the 21T4 and 21L4 sheets, respectively. A regular decrease in slope is observed with increasing moment of inertia of the ribs, as is illustrated by figure 8. Values of the slopes determined from the graphs of δ against P are listed in table II.

It was hoped originally that Southwell's method (reference 2) might be applied to the determination of the limiting values of the moment of inertia, but after trial the method was set aside, as were several empirical methods, in favor of the following.

Trial showed that the relation

$$S = S_0 \ e^{-\lambda b'} \qquad (1)$$

holds satisfactorily for the stiffening ribs that are not too deep. The limiting value of rib depth was therefore defined as the value of b' for which S is equal to S_0/e. In almost all cases the limiting value of rib depth, as defined above, occurred in the region in which the relation (equation (1)) was valid within the limits of the experimental error.

The procedure for finding the limiting values of the rib depth b_L was to plot the logarithms of the slopes of the δ-against-P curves against the rib thickness b'. The intercept on the logarithmic axis yielded S_0 and the values of b_L then were read directly from the curves. Owing to limitation of data, it was helpful in many cases to plot S against b' to serve as a guide in properly weighting data.

Illustrative curves of S against b' and $\log S$ against b' are given in figures 9 to 11. Table III lists the summary of the limiting values of γ obtained as explained previously, with pertinent information for all panels. Figure 13 and table IV list Timoshenko's values of γ against β, taken from reference 1, for simply supported panels with uniform boundary stresses. Figures 14 to 16 show the experimentally determined values of γ for the particular panels of this report plotted along with related values given by Timoshenko. The moments of inertia of the ribs from which the values of γ were calculated were obtained from the relation

$$I = 1/3 \ a'b'^3 \qquad (2)$$

neglecting the effect of the associated sheet, the screw holes, and the screws that held the rib to the sheet.

Since it was a priori questionable whether the calculated values of the rib moments of inertia were "made good," the effective values were measured for a particular case for each thickness of rib. To the rib there was attached a strip of 0.040 inch 17S-T sheet 1.22 inches wide, using 6-32 brass screws spaced 3/4 inch between centers just as in the experimental panels. The stiffener was then supported horizontally between knife edges 23.6 inches apart and loaded at the center to produce bowing in the same sense as that experienced on the test panels — that is, with the rib concave toward the sheet, placing the screw holes in compression.

For a concentrated load P on a beam, the maximum (central) deflection is given by (reference 3)

$$\delta = \frac{Pl^3}{48\ EI}\left\{1 + 3.12\,(2c/l)^2\right\} \qquad (3)$$

or, approximately,

$$\delta = \frac{Pl^3}{48\ EI} \qquad (3')$$

For each rib the deflections corresponding to several different loads were measured by a micrometer screw, and average values of I were calculated from equation (3'). These represent effective moments of inertia for the rib plus a strip of sheet of width approximately 15 times the sheet thickness on each side of its center line. These effective values are compared with the moments of inertia calculated for the ribs plus sheet relative to their neutral axis in table V, which also includes for convenience the values $1/3\ a'b'^3$. In figure 12 the effective moments of inertia and calculated values relative to the neutral axis are shown as ordinates with the $1/3\ a'b'^3$ values as abscissas. The values of $\Delta = A/bh$ for the ribs also are given in table V.

Effective Shear Modulus

Values of the effective shear modulus were obtained for each of the nine sheet panels using stiffeners of various depths. These were based on shear measurements made with dial gages attached by tabs to the lower ends of the side stiffeners (fig. 3) and connected by aluminum wire to measure the changes in the lengths of the sheet diagonals (fig. 5). The shear strain was calculated from the relation

$$\gamma = \frac{c(dc - dc')}{2\ ab} \qquad (4)$$

Graphs of shear stress against strain were drawn, such as figure 17, and the shear moduli taken as the values of the slopes of secants drawn from the origin to points on the curves corresponding to stresses of 1000, 2000, and 3000 pounds per square inch, respectively. These shear moduli together with values of the parameter $h/b\ \sqrt{E/\tau}$ are presented in table VI.

The data listed in table VI for unstiffened sheets represent preliminary measurements of shear taken before the sheet was drilled for ribs. Thus 11T0 and 11L0 represent similar, unstiffened sheets and should have equal moduli.

Effect of Bending of Side Stiffeners

The method in which the sheet panels were supported in the testing jig permitted a possible bowing of the side stiffeners toward the center of the panel. The magnitude of this bowing and its effect were investigated. A Whittemore gage was used to span the sheet panel and to measure the slight bending of the side stiffeners toward each other as the sheet was loaded. With a 30-inch sheet without ribs and at the highest loads, the maximum inward bending of the side stiffeners was about 0.002 inch for compressive loading ($k = 0$) and about 0.025 inch for shear loading ($k = 10\frac{1}{4}$).

Use of Spreaders

To study the effect of restraining the inward bowing of the side stiffeners, steel spreaders were made of drill rod provided with end pieces machined to bear against the side stiffeners of the sheet panel without touching the sheet. These were attached as shown in figure 3. With two such spreaders spaced symmetrically on each side of the 30-inch panel, the maximum inward bowing of the side stiffeners was about 0.001 inch for compressive loading and about 0.013 inch for shear loading.

Measurements of rib bowing and of shear of the sheet panels were made with and without spreaders for all sheets except those having longitudinal ribs too deep to permit clearance of the spreaders. As many as four pairs of spreaders were used (33T sheet), placed midway between the transverse ribs. These measurements showed that the effective shear modulus of a sheet was increased about 5 percent by the presence of the spreaders. It was not sensitive to the placing of the spreaders or the extent to which they were tightened. On the other hand, the magnitude and direction of the rib bowing were greatly influenced by the addition of spreaders. All data reported on bowing were taken without spreaders. Insofar as values of effective shear moduli are concerned, it is concluded that the testing jig used yielded results substantially the same as those that would be obtained with a jig that provided the side stiffeners with continuous support against inward bowing.

DISCUSSION

Limiting Values of Gamma and Moment of Inertia

Figures 14 to 16 show the principal results. A similarity exists between the experimental values for the particular panels of this report and Timoshenko's theoretical values for simply supported panels with uniform boundary stresses, but the experimental values are in all cases higher. The experimental points are based upon moments of inertia computed by $1/3\ a'b'^3$ without regard to sheet or screws or screw holes. The use of $1/3\ a'b'^3$ follows Timoshenko, as shown by example in the reference given; its use here is justified by the evidence shown in table V that the effective and computed values of the moments of inertia of the ribs are in quite close agreement for all ribs up to 1 inch depth for the particular case tried.

In the case of longitudinal ribs, the experimental values should be expected to be somewhat too high as the Δ values were high for the limiting ribs (tables III and V).

It should be emphasized that Timoshenko's theoretical values for the limiting gammas are based on sheet panels with all edges simply supported and with uniform boundary stresses. The experimental panels of this report were not designed to duplicate the conditions of Timoshenko's calculations but were chosen as a feasible case with which to experiment and one for which the results would have considerable practical value.

The comparison depends on the definition adopted in the experimental work for the limiting moment of inertia. If a value corresponding to $S_o/10$ were accepted, for instance, much greater values would result. Just as a centrally loaded column deflects because of lack of initial straightness, so these ribs may be expected to deflect at the initial loads as a result of the imperfections of the sample and the eccentricity of the ribs. As will be pointed out under Effective Shear Modulus, all sheets as well as ribs did show lateral deflection at the initial loads and anything corresponding to calculated critical buckling stress is quite suppressed and not directly observable. Perhaps, as suggested under the following section, the limiting value should be based on the attainment of limiting rigidity, but experimentally this is indirect.

Effective Shear Modulus

Figure 18 and table VII show the variation of effective shear modulus for sheet panels against a parameter defined as $h/b \sqrt{E/\tau}$ as given by Lahde and Wagner (reference 4) together with the experimental values obtained for the panels of this report. The experimental values plotted are averages, for each panel, over the range of rib depths employed. The slopes of the experimental curves as drawn are higher than those of the theoretical curves. For the 11T and 11L panels, there is one value of G_e higher than that for a panel in pure shear. This probably results from the fact that the ribs and the frame brace the panel in such a way as to bring Young's modulus into action.

All panels and ribs were in all cases observed to start lateral displacement at the lowest loads. Thus, theoretical buckling load could not be directly related to these observations, a fact which accords with other workers' results.

Figure 19 and table VIII show how the effective shear modulus for each panel varies with the moment of inertia of the ribs. This in itself provides a second method of determining the limiting rib, and qualitatively corroborates the procedure employed in this report for obtaining the limiting moments of inertia.

CONCLUSIONS

Limiting Gammas

Since the sheets and the ribs of the panels of this report showed lateral deflection at the initial loads, some method of defining the limiting rib was necessary. When the limiting gammas for these panels, as obtained by the empirical method for finding the limiting rib depth as devised in this report, are plotted as a function of length-width ratio and brought into juxtaposition to those obtained theoretically by Timoshenko for panels with all edges simply supported and with uniform boundary stresses, a similarity of the relations is observed, but in all cases the experimental values are higher. The conditions of simple edge support and uniform boundary stresses cannot be considered to obtain for the experimental panels.

In all cases the experimental ribs were mounted upon only one side of the sheet. However, the ribs may not have bent with the neutral axis in the plane of the sheet, thus offering a maximum moment of inertia, as is assumed by Timoshenko.

The experimental values cover the cases of panels in compression and in shear with one to three transverse ribs and in compression and in shear with one longitudinal rib.

Effective Shear Modulus

The experimental values of the effective shear (secant) modulus of the panels are in as good agreement as could be expected with the values published by Lahde and Wagner.

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State College, Pa., September 16, 1943.

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TABLE I.- DIMENSIONS OF TEST PANELS

[b = 10.63 in. for all panels]

Sheet type	Sheet thickness (in.)	a (in.)	w (in.)	l (in.)	$\frac{c + c'}{2}$ (in.)
11 T	0.0392	10.63	10.22	8.87	13.51
11 L	.0408	10.63	10.20	8.84	13.50
21 T	.0400	21.25	10.20	19.39	21.94
22 T	.0403	21.25	10.22	19.39	21.94
21 L	.0392	21.25	10.20	19.37	21.94
31 T	.0404	31.85	10.22	29.97	31.64
32 T	.0393	31.85	10.20	29.97	31.64
33 T	.0401	31.85	10.19	29.97	31.63
31 L	.0389	31.85	10.22	29.97	31.63

TABLE V.- COMPARISON OF CALCULATED AND EFFECTIVE MOMENTS OF INERTIA FOR RIBS

Rib cross section (in.)	$I = 1/3\ a'b'^3$	I calculated (neutral axis) (in.^{4})	I effective (in.^{4})	Δ
1/8 x 3/8	2.45×10^{-4}	2.24×10^{-4}	2.32×10^{-4}	0.11
1/4 x 3/8	19.60	11.58	11.28	.22
1/2 x 3/8	156.2	67.1	65.6	.44
3/4 x 3/8	527	196	193	.66
1 x 3/8	1275	441	346	.88

TABLE II.- SLOPES OF δ AGAINST P CURVES

[δ/P in./lb]

Sheet code	$k = 0$	$k = 1$	$k = 2\frac{9}{16}$	$k = 5\frac{1}{8}$	$k = 10\frac{1}{4}$
11T 1	3.2×10^{-6}				3.6×10^{-6}
2	1.7		2.6×10^{-6}	4.1×10^{-6}	12.1
4	4.6		16	21	27.5
8	12.5		20	30	40.0
11L 1	1.1		1.2	1.2	1.2
2	6.3		7.1	8.9	10.6
4	16.5		18	22	26.0
8	24.5		24	32	42.0
21T 1	0.5				2.5
2	1.2	1.2×10^{-6}	1.6	4.6	7.1
4	2.7	3.0	4.3	17.4	24.0
8	13.3	16	22	28	50.3
21L 1	6.1	6.5	6.5	6.5	6.8
2	16.2		17	18	26.7
4	25.5		28	30	41.3
8	38.0		33	33	49.2
22T 1					
2	2.5		2.5	2.5	2.5
4	3.8		3.8	4.6	9.3
8	8.0		8.0	13	19.4
31T 1					
2	2.1	2.1	2.5		5.3
4	3.3	3.3	4.6	12.4	23.5
8	7.3	7.3	9.5	26	45.0
31L 1	13.5	16.6	19.0	19.0	21.0
2	33.5	33.5	37.0	40.0	42.5
4	31.2	36	49	60	68.0
8	44.5	45	49	60	84.0
32T 1					
2	2.0		2.0	2.6	2.6
4	1.4		7.6, 9.8	10.4	10.4
8	5.8		15.5	19.3	25.0
33T 1	1.5		1.6		2.0
2	1.5	2.0	2.0	3.4	4.8
4	4.3	4.3	6.0	7.5	10.5
8	11.0	14.3	14.3	19.3	23.2

TABLE III

SUMMARY OF CALCULATION OF LIMITING VALUES OF GAMMA BY EXPERIMENTAL METHOD

Sheet code	k (in.)	S_o	$\frac{S_o}{e}$	b_L (in.)	b_L^3 (in.^{3})	I_L (in.^{4})	B	γ_L	$\beta = \frac{a}{b}$
11T 21T 31T	0	33 65 33	12.5 23.9 12.5	0.125 .079 .09	195×10^{-5} 49.3 73	244×10^{-6} 61.6 19.3	2,510 635 940	3.8 .96 1.4	1 2 3
22T 32T	0	16.7 25	6.15 9.2	0.168 .085	475 61.5	594 76.9	6,120 792	9.2 1.2	2 3
33T	0	20.6	7.6	0.18	385	730	7,500	11	3
11T 21T 31T	$10\frac{1}{4}$	60 94 94	22.1 34.6 34.6	0.311 .190 .174	3010 686 528	3760 357 660	38,700 8,820 6,800	58 6.7 3.4	1 2 3
22T 32T	$10\frac{1}{4}$	36.5 59	13.4 21.7	0.19 .145	686 306	860 382	8,850 3,940	6.7 2.0	2 3
33T	$10\frac{1}{4}$	36	13.3	0.24	1380	1730	17,800	9.0	3
11L 21L 31L	0	39.6 46.8 52.6	14.6 17.2 19.4	0.275 .473 .725	2090 10600 38200	2610 13300 47700	26,900 137,000 492,000	41 207 744	1 2 3
11L 21L 31L	$10\frac{1}{4}$	66 76 104	24.3 28.0 38.3	0.27 .42 .60	1970 7400 21600	2460 9250 27000	25,400 95,200 278,000	38 72 140	1 2 3

TABLE IV.- TIMOSHENKO'S VALUES OF LIMITING GAMMA FOR PANELS

WITH SIMPLY SUPPORTED EDGES

Panel in compression, one transverse rib

$\beta = \frac{a}{b}$	$\gamma = \frac{B}{bD}$
0.50	12.6
.60	7.18
.70	4.39
.80	2.80
.90	1.82
1.0	1.26
1.2	.433
1.41	0

Panel in compression, three transverse ribs

$\beta = \frac{a}{b}$	$\gamma = \frac{B}{bD}$
0.60	101
.80	42.6
1.0	21.7
1.2	12.4
1.4	7.71

Panel in shear, one rib transverse to "a" dimension

$\beta = \frac{a}{b}$	$\gamma = \frac{B}{aD}$
2	0.83
1.5	2.9
1.25	6.3
1	15

Panel in shear, two ribs transverse to "a" dimension

$\beta = \frac{a}{b}$	$\gamma = \frac{B}{aD}$
3	0.64
2.5	1.37
2	3.53
1.5	10.7
1.2	22.6

Panel in compression, one longitudinal rib

$\beta = \frac{a}{b}$	$\gamma = \frac{B}{bD}$	
0.6	5	
1.0	10	
1.4	15	$\Delta = 0.05$
1.6	20	
2.0	25	
.6	5	
1.0	10	
1.2	15	$\Delta = 0.10$
1.6	20	
1.8	25	
.6	5	
.8	10	
1.2	15	$\Delta = 0.20$
1.4	20	
1.6	25	

TABLE VI.– SUMMARY OF EFFECTIVE SHEAR (SECANT) MODULUS

OF PANELS BY EXPERIMENTAL METHOD

$[k = 10\frac{1}{4}]$

Sheet code	Shear stress, lb/in.^{2}	1000	2000	3000
	$\frac{h}{b}\sqrt{\frac{E}{\tau}}$	0.38	0.27	0.22
11TO			3.08 x 10^6	2.52 x 10^6
8			3.85	3.53
4		4.54 x 10^6	3.48	3.00
2		4.54	4.00	3.66
11LO		3.94	2.90	2.80
8		4.45	3.34	3.08
4		4.50	4.55	4.62
2		5.69	3.92	3.62
1		4.85	3.64	3.62
21TO		3.33	2.31	1.83
8		4.44	2.44	1.91
4		3.70	2.67	2.33
2		3.70	2.76	2.66
21LO		3.08	2.16	1.82
8		3.64	2.74	2.29
4		3.50	2.67	2.36
2		3.64	2.86	2.66
1				
22TO		3.64	2.22	1.85
8		3.03	2.47	2.40
4		2.50	2.40	2.58
2		3.84	3.26	3.24
31LO		2.00	1.48	1.25
8		2.22	1.91	1.64
4		2.98	2.22	1.94
2		2.98	2.38	2.16
1		2.70	2.28	2.13
31TO				
8		2.35	2.08	1.56
4		1.96	1.43	1.72
2		2.00	1.60	1.68
32TO				
8		2.04	2.00	1.63
4		2.60	2.41	2.05
2		2.50	2.33	2.05
33TO				
8		2.18	2.06	1.89
4		2.56	2.20	2.04
2		2.28	2.15	1.97

TABLE VII.- AVERAGE VALUES OF $\frac{G_e}{E}$ OF PANELS BY EXPERIMENTAL METHOD, $k = 10\frac{1}{4}$, AS PLOTTED IN FIGURE 19

Sheet	Shear stress, lb/in.^{2} . .	1000	2000	3000
	$\frac{h}{b}\sqrt{\frac{E}{\tau}}$	0.38	0.27	0.22
11T		0.440	0.348	0.309
11L		.455	.356	.345
21T		.363	.248	.212
21L		.336	.252	.222
22T		.315	.242	.244
31L		.250	.199	.177
31T		.204	.165	.160
32T		.231	.218	.185
33T		.227	.208	.191

TABLE VIII.- VALUES OF I/I_L AND G_e, $k = 10\frac{1}{4}$, AS PLOTTED IN FIGURE 20

Sheet code	$\beta = \frac{a}{b}$	Rib thickness (in.)	I (in.^{4})	I_L (in.^{4})	I/I_L	G_e, av. effective shear modulus (lb/in.^{2})
11T	1.00	0.00	0.00	0.00376	0.00	3.36 × 10^6
		.125	.000245		.0652	3.69
		.25	.00196		.521	3.67
11L	1.00	0.00	0.00	0.00246	0.00	3.21
		.125	.000245		.0996	3.62
		.25	.00196		.796	4.65
		.50	.0156		6.34	4.41
		1.00	.125		50.8	4.04
21T	2.00	0.00	0.00	0.000857	0.00	2.72
		.125	.000245		.286	2.93
		.25	.00196		2.29	2.90
		.50	.0156		18.2	3.04
21L	2.00	0.00	0.00	0.00925	0.00	2.35
		.125	.000245		.0265	2.56
		.25	.00196		.212	2.84
		.50	.0156		1.69	3.05
		1.00	.125		13.5	5.53
22T	2.00	0.00	0.00	0.00086	0.00	2.57
		.125	.000245		.285	2.63
		.25	.00196		2.28	2.49
		.50	.0156		18.1	3.45
31L	3.00	0.00	0.00	0.0270	0.00	1.58
		.125	.000245		.00908	1.94
		.25	.00196		.0725	2.38
		.50	.0156		.577	2.51
		1.00	.125		4.63	2.37
31T	3.00	0.00	0.00	0.000660	0.00	
		.125	.000245		.371	*1.82
		.25	.00196		2.97	*1.84
		.50	.0156		23.6	*1.84
32T	3.00	0.00	0.00	0.000382	0.00	
		.125	.000245		.641	1.89
		.25	.00196		5.13	2.35
		.50	.0156		40.8	2.26
33T	3.00	0.00	0.00	0.00173	0.00	
		.125	.000245		.142	2.04
		.25	.00196		1.13	2.27
		.50	.0156		9.02	2.13

*Averaged over two values only.

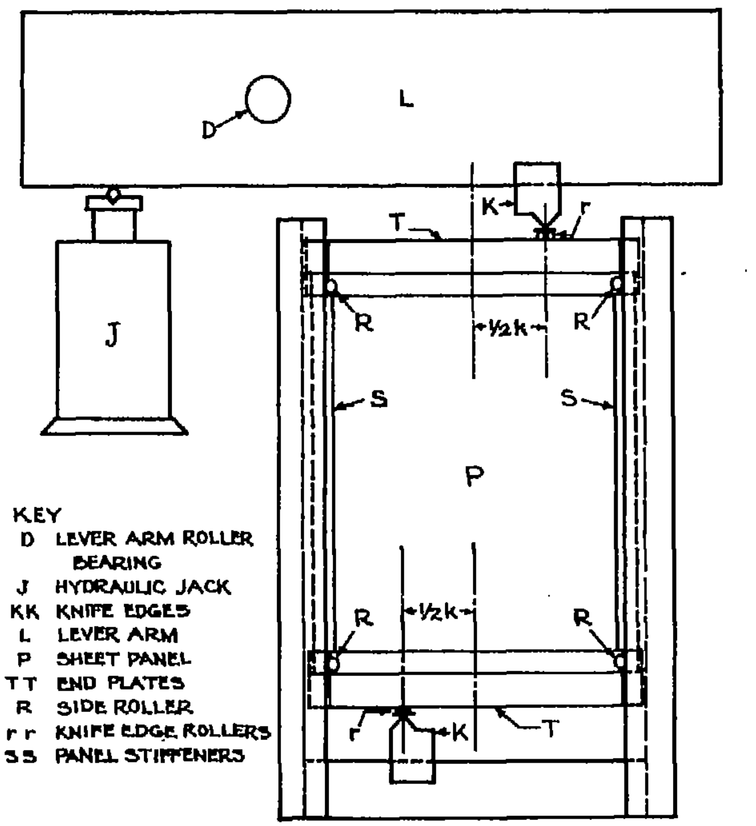


FIG. 1.- SKETCH SHOWING METHOD OF LOADING SHEET PANEL IN COMPRESSION OR COMBINED COMPRESSION AND SHEAR.

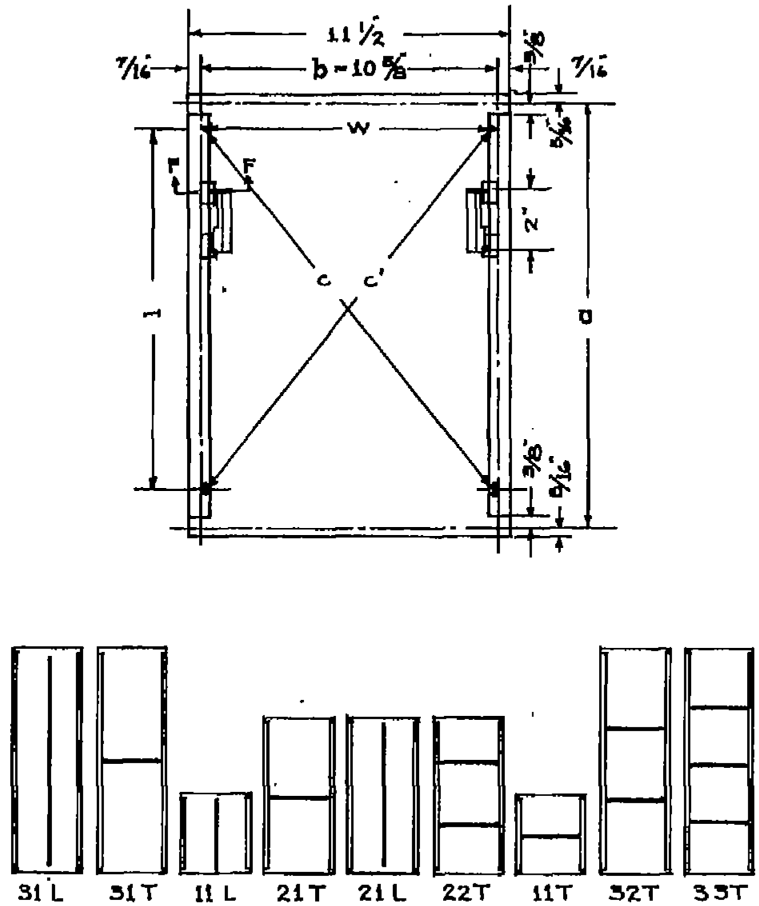


FIG. 5.- FORMS AND DIMENSIONS OF TEST PANELS

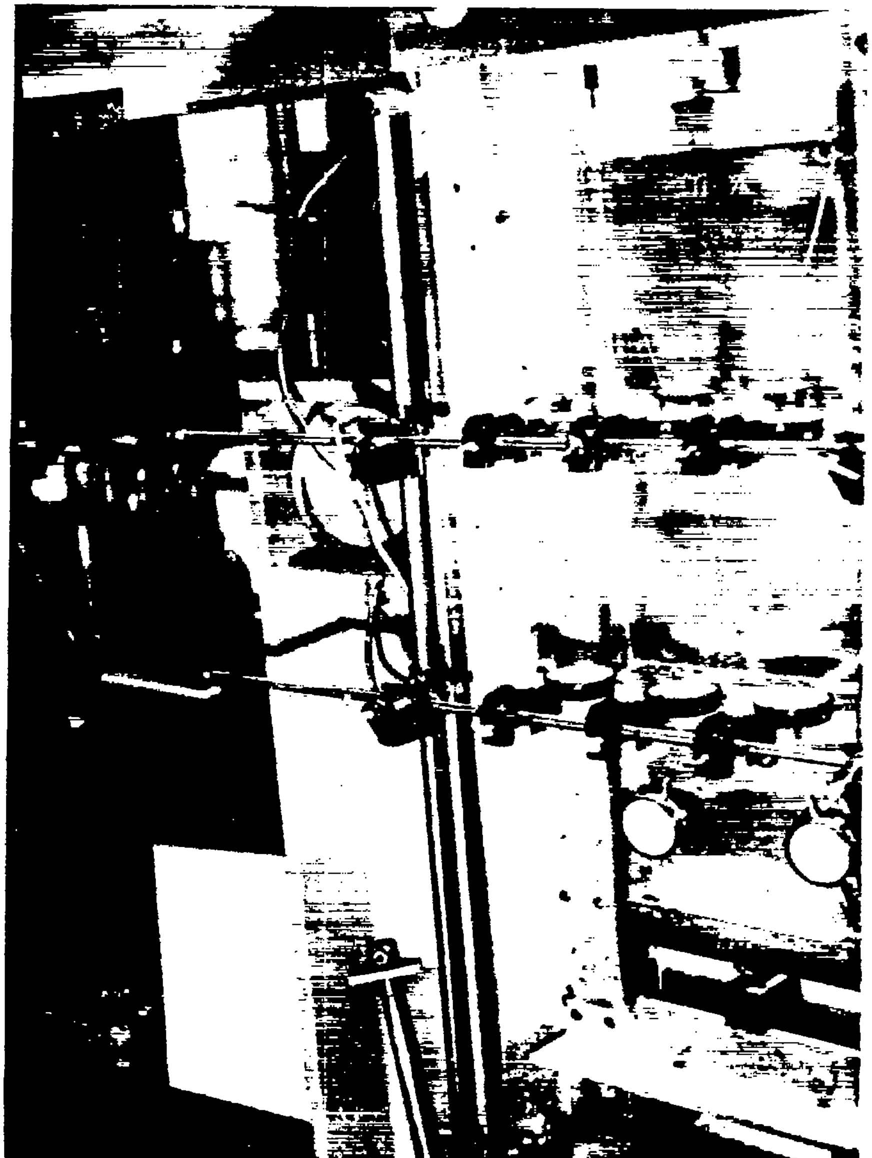


Figure 2.- Testing jig for loading sheet panels.

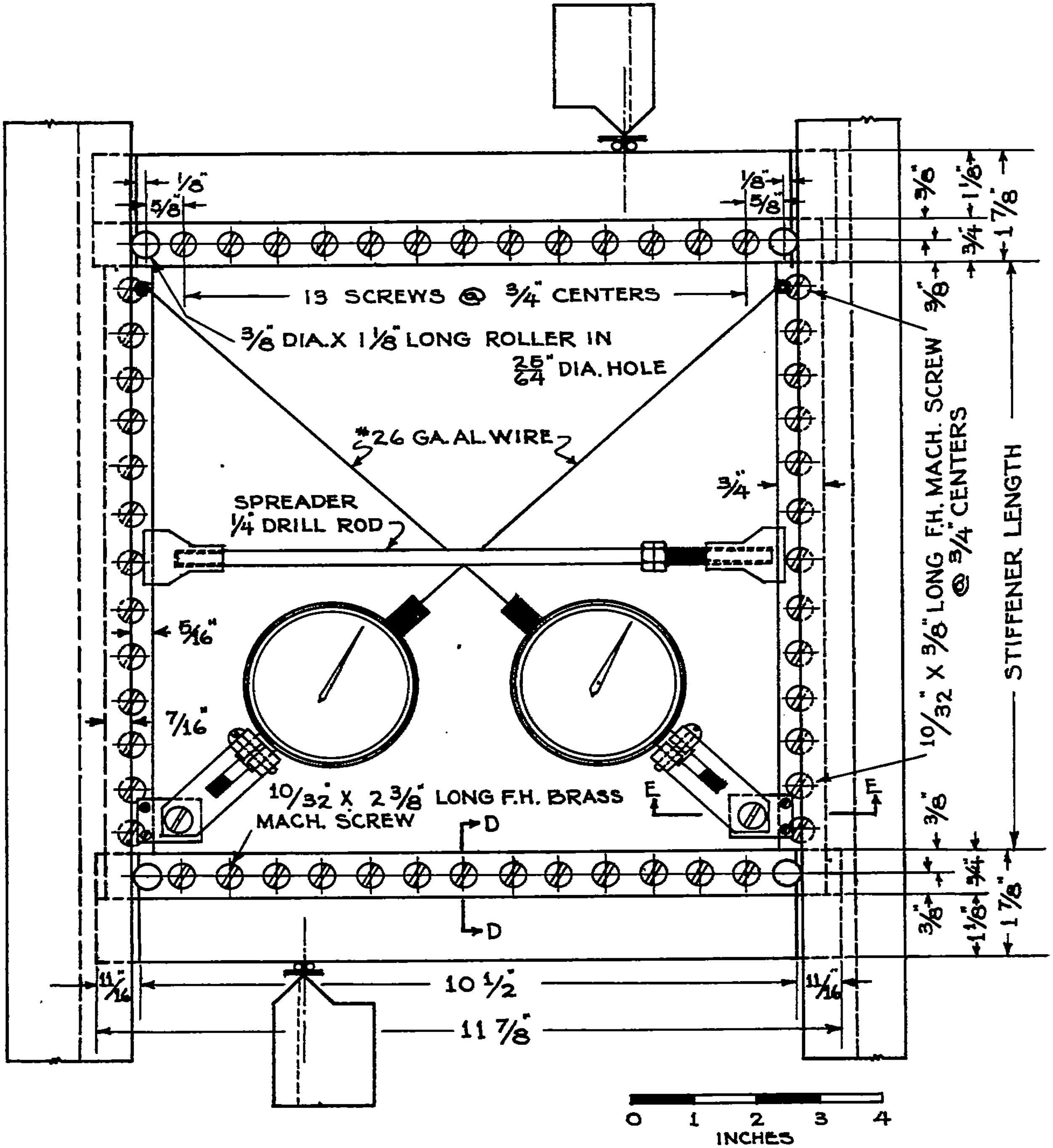
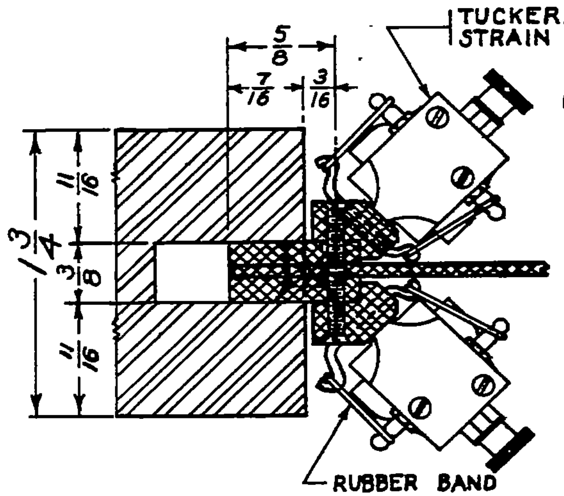
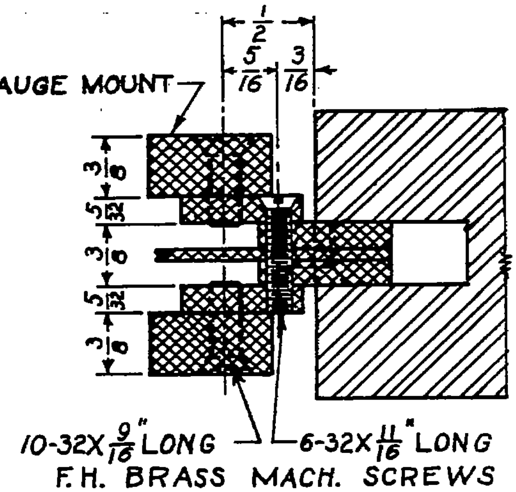


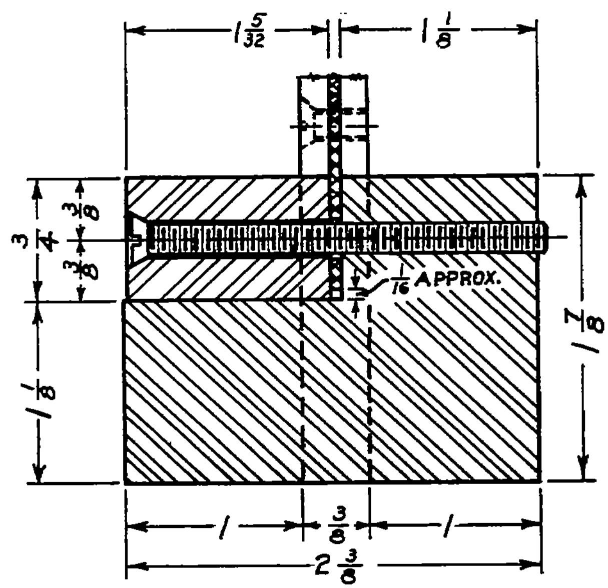
FIG. 3. - MOUNTING OF SHEET PANEL



SECTION F-F, FIG.5



SECTION E-E, FIG.3



SECTION D-D, FIG.3

FIG.4.-GAUGE MOUNTS AND SHEET END PLATES

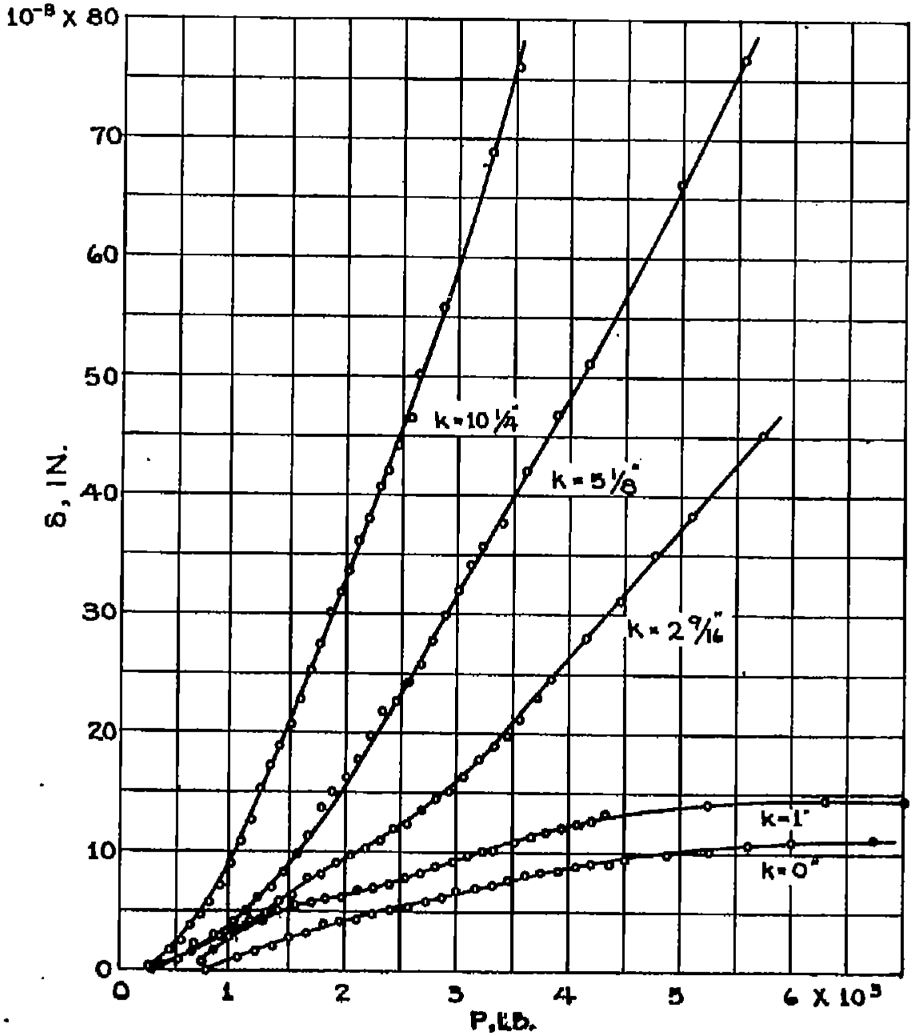


FIG. 6.-DEFLECTION vs LOAD, SPECIMEN 21T4

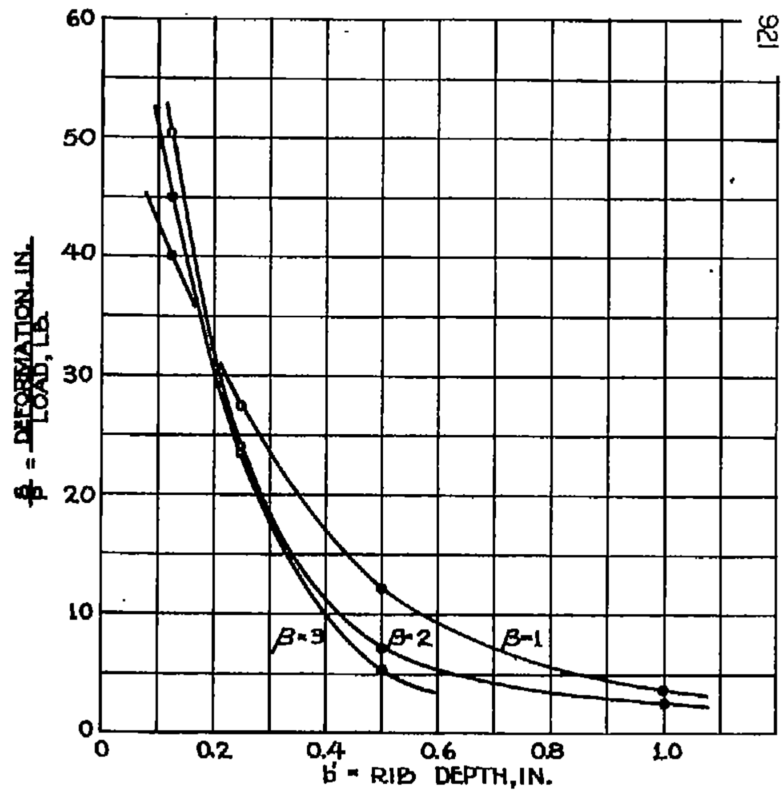


FIG. 9.-RIB BOWING, SPECIMEN 1T, k=10¼IN

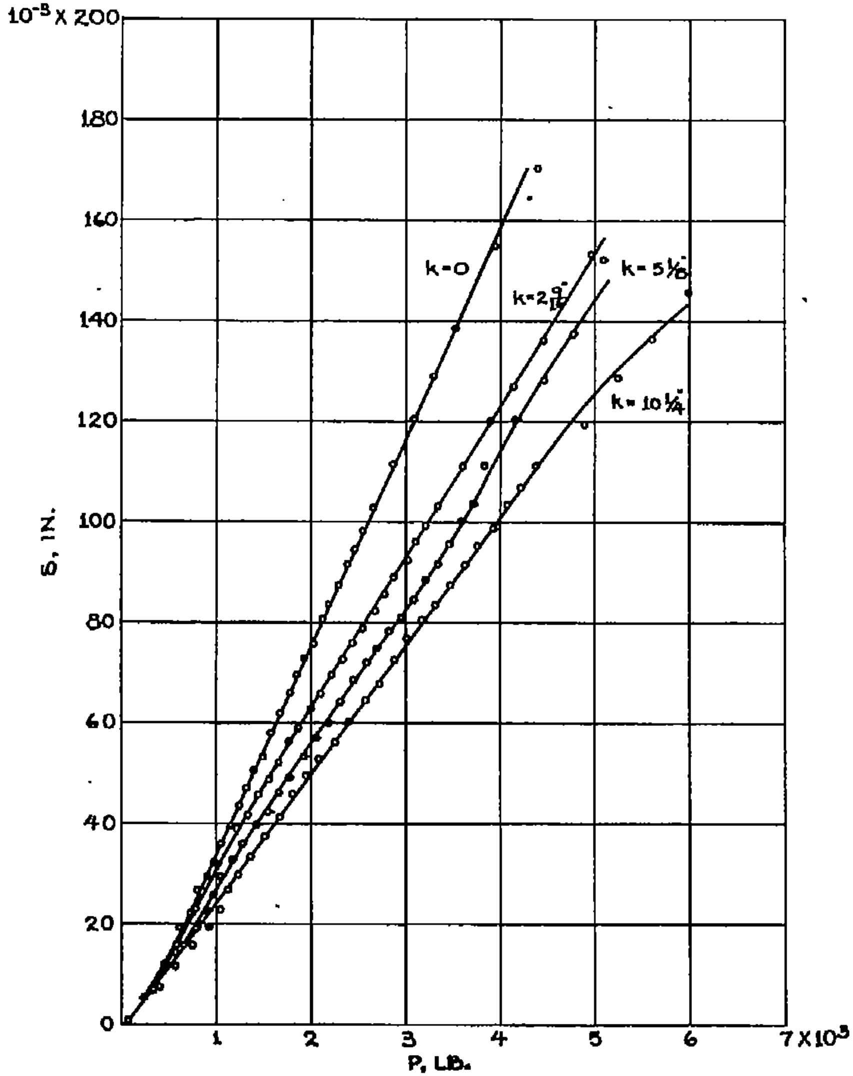


FIG. 7.- DEFLECTION vs LOAD, SPECIMEN 21L4

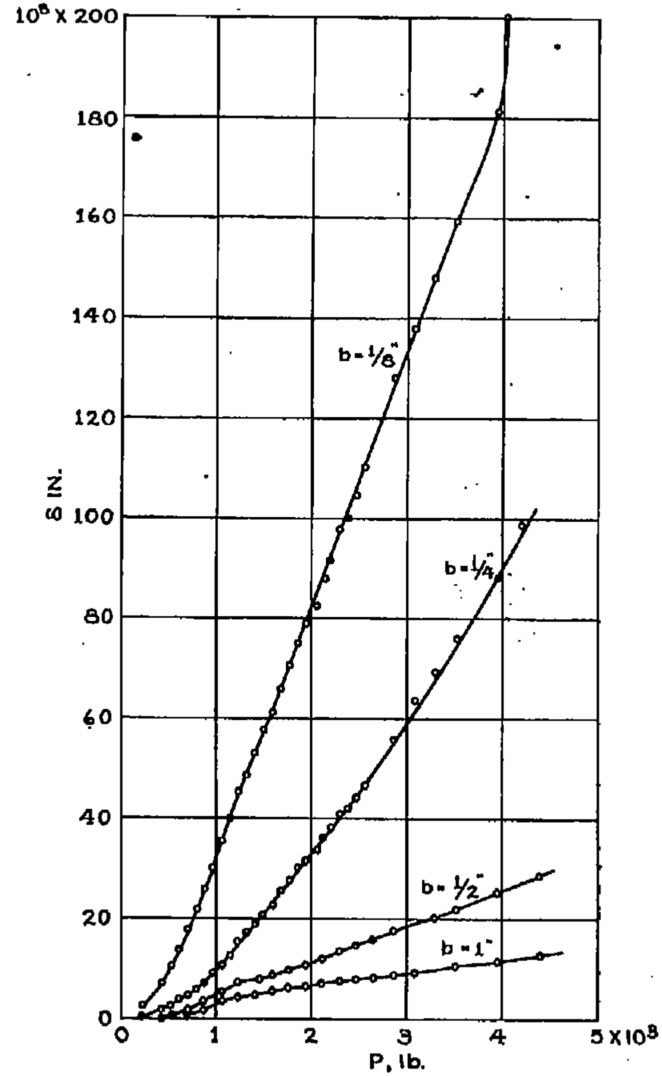


FIG. 8.- DEFLECTION vs LOAD, SPECIMEN 21T

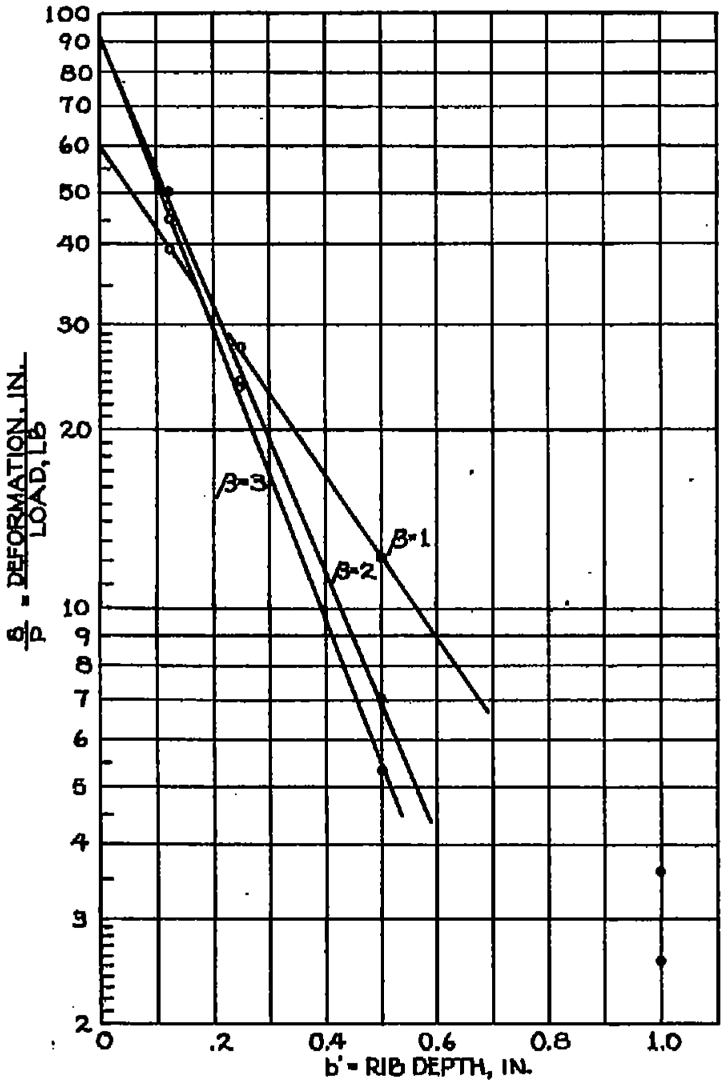


FIG.10.-RIB BOWING, SPECIMEN 1T, k = 10¼ IN.

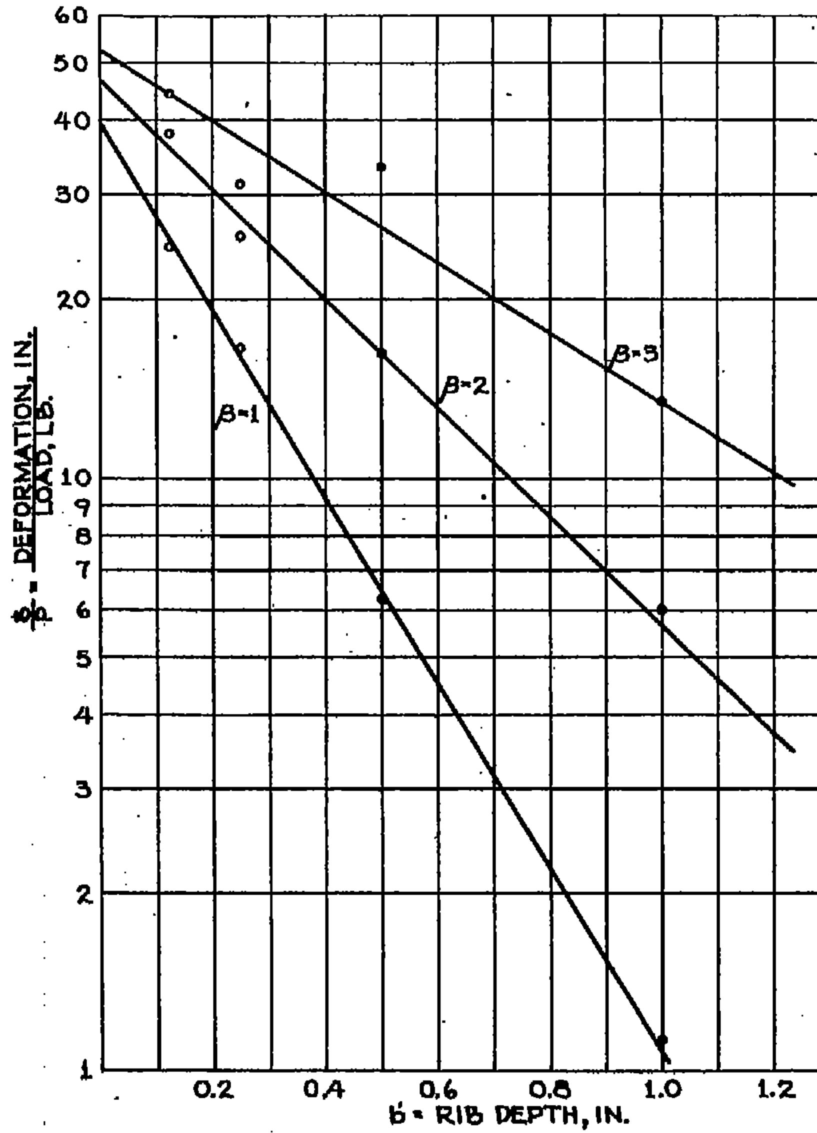


FIG. 11.- RIB BOWING, SPECIMEN 1L, k = 0

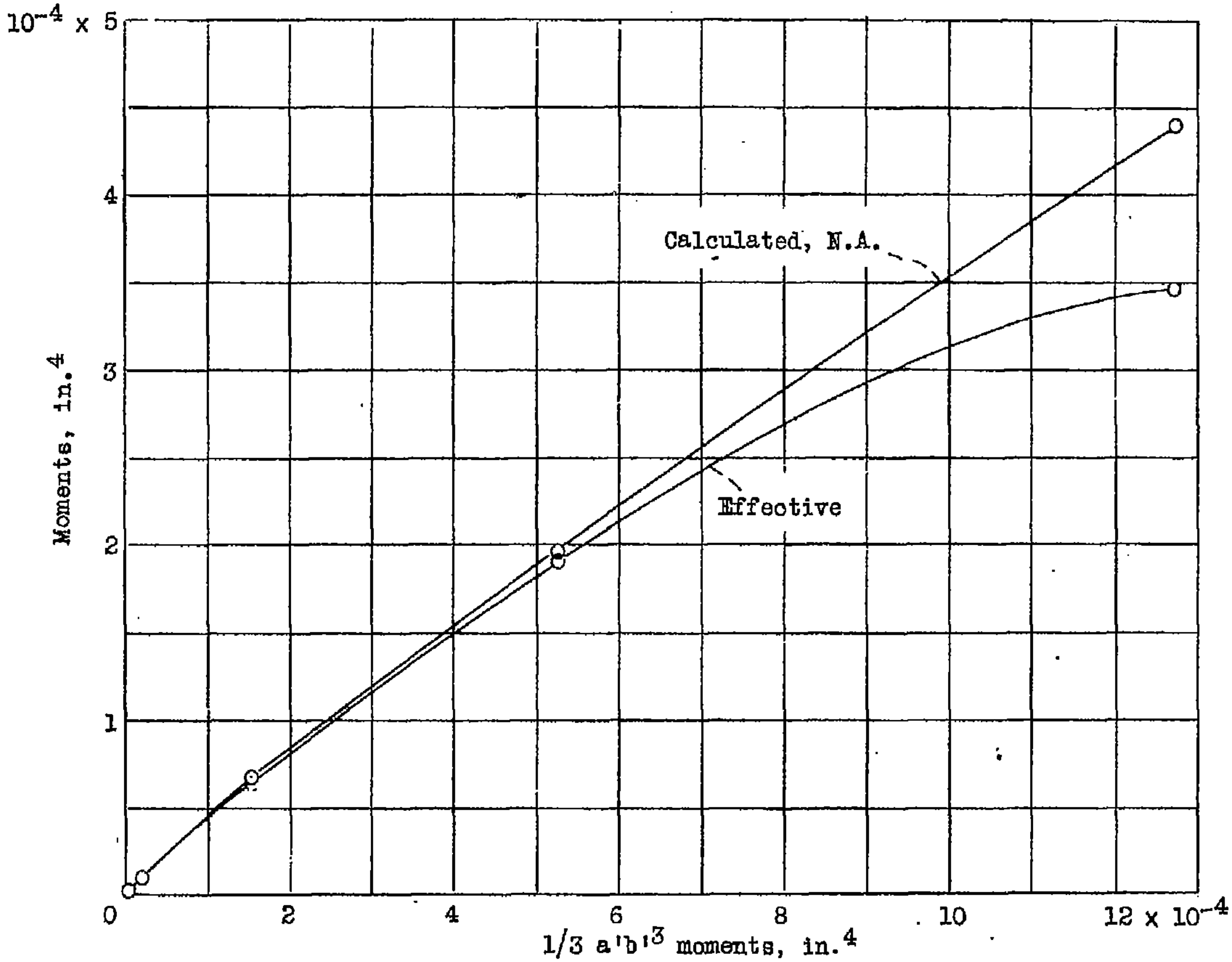


Figure 12.- Calculated and effective moments of inertia for rectangular stiffeners.

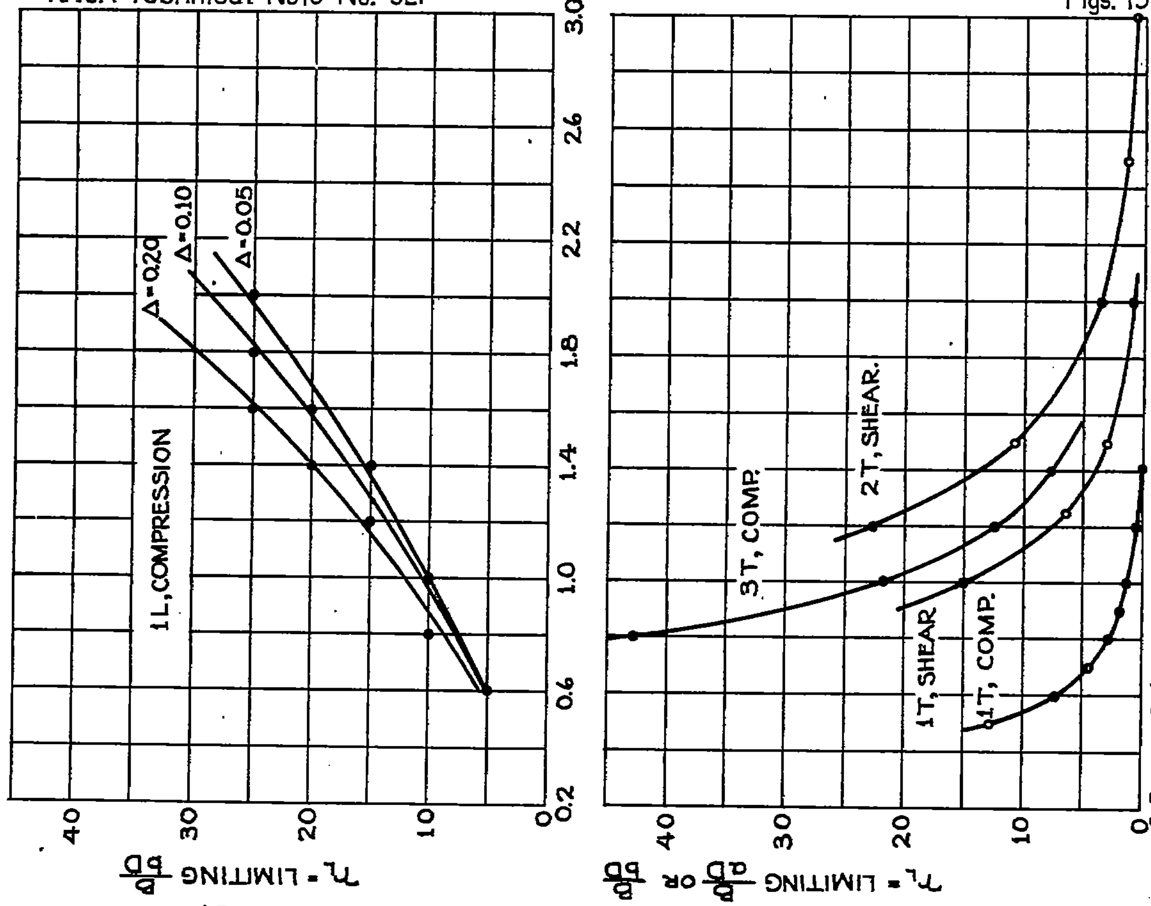


FIG. 13.- SUMMARY OF TIMOSHENKO VALUES OF η_L vs β

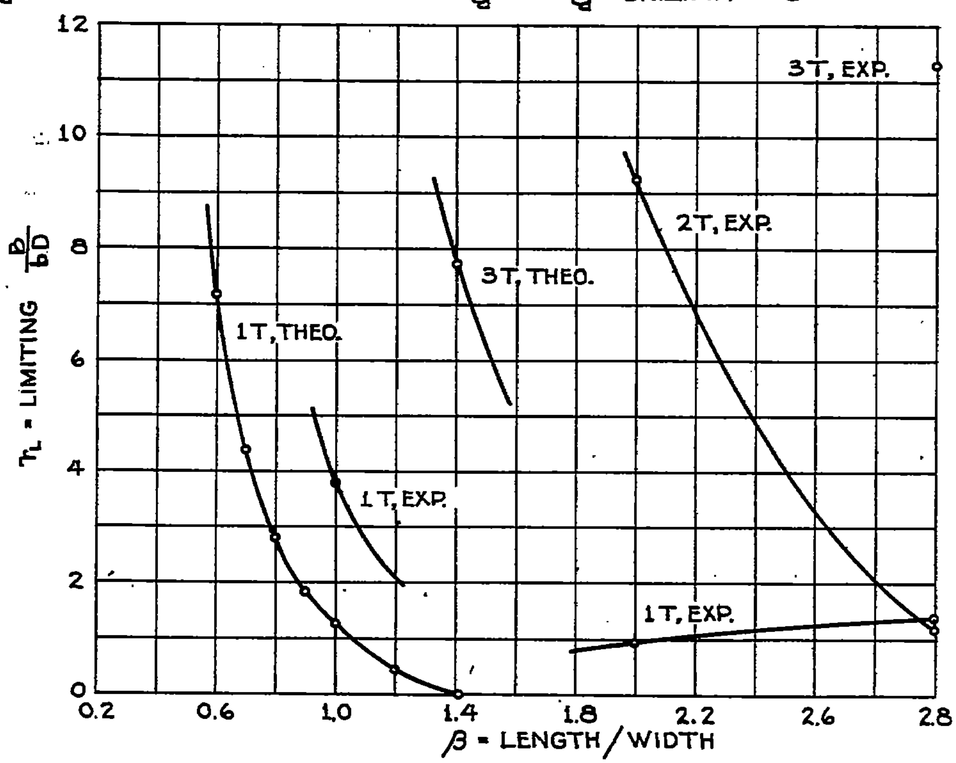


FIG.14.-DEFORMATION UNDER COMPRESSIVE LOADING, k = O

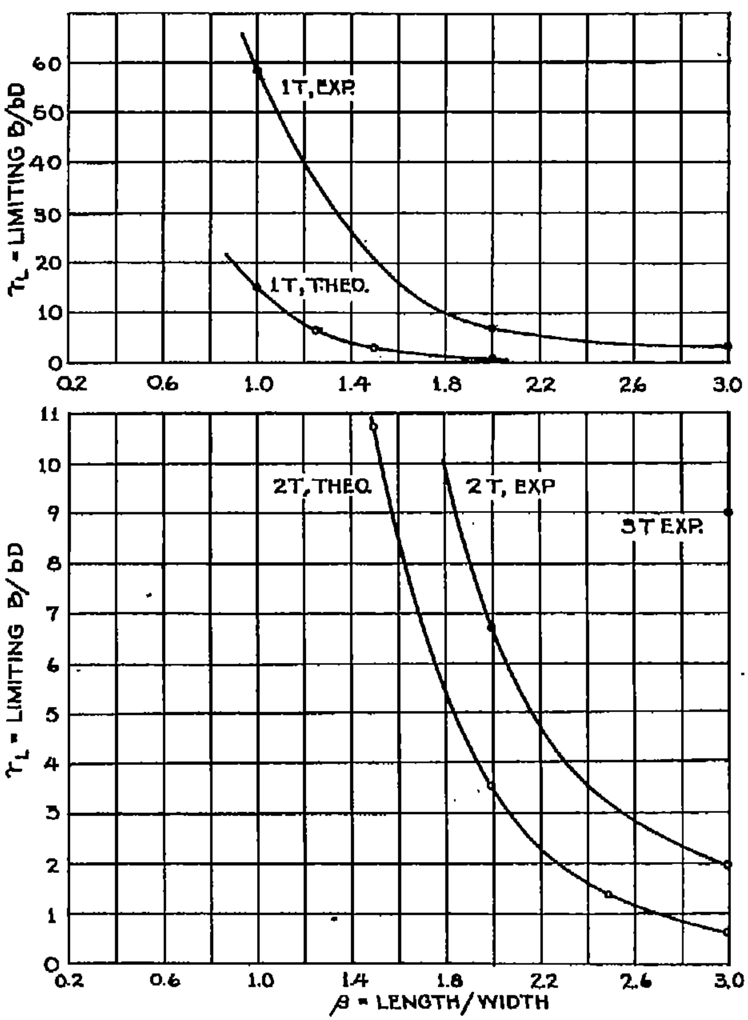


FIG. 15.-DEFORMATION UNDER SHEAR LOADING, k = 10¼

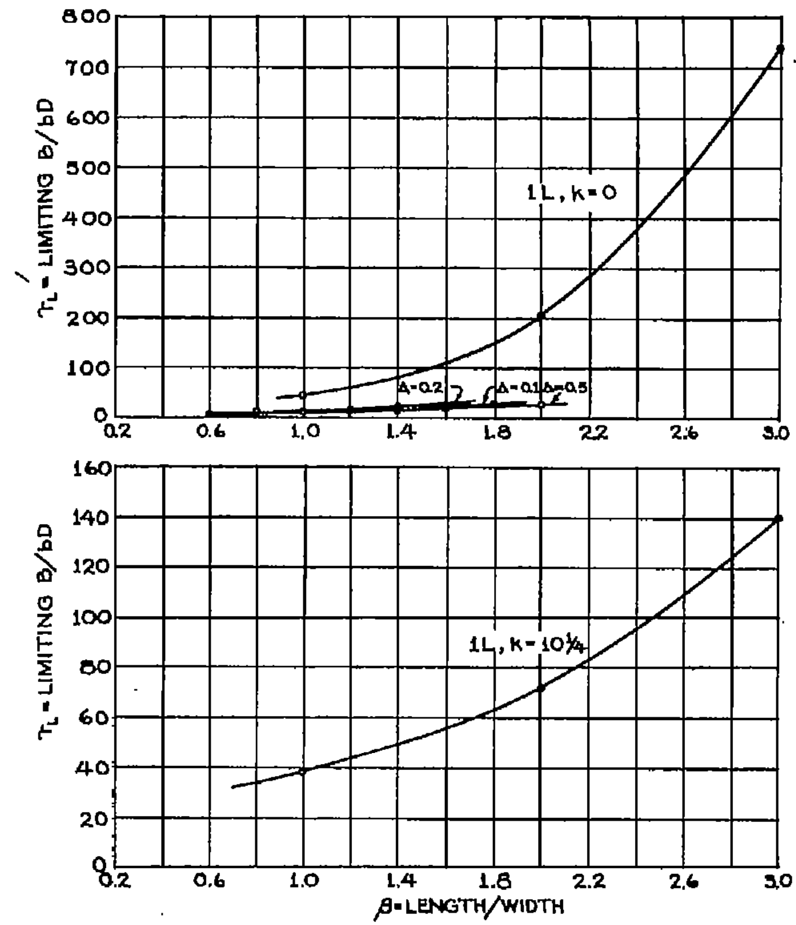


FIG. 16.-DEFORMATION UNDER COMPRESSIVE LOADING

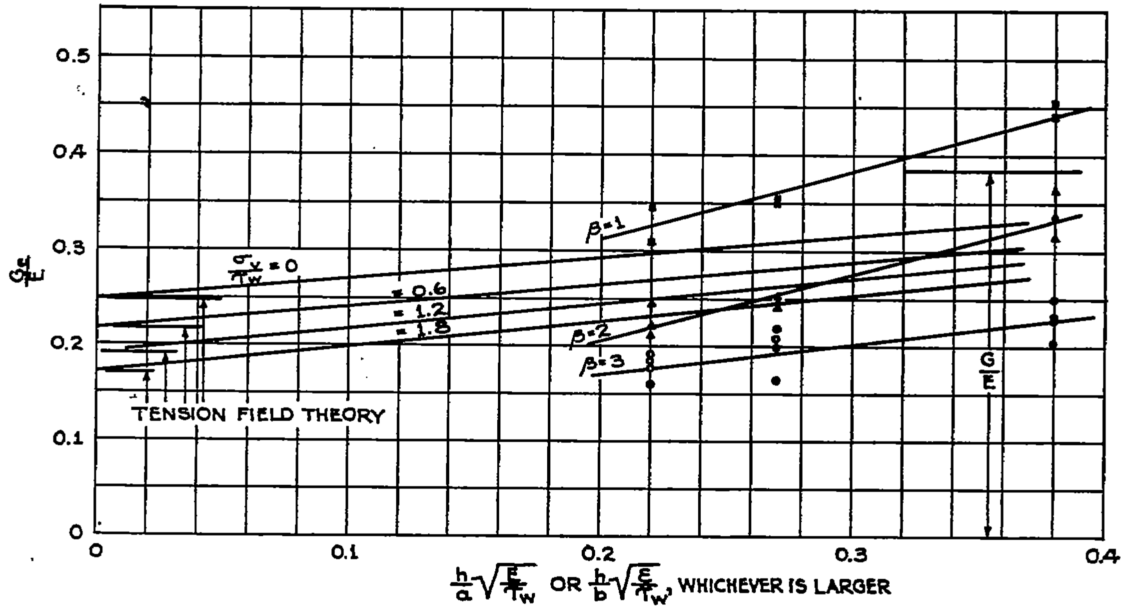


FIG. 18.-EFFECTIVE SHEAR MODULUS, EXPERIMENTAL COMPARED WITH LAHDE AND WAGNER

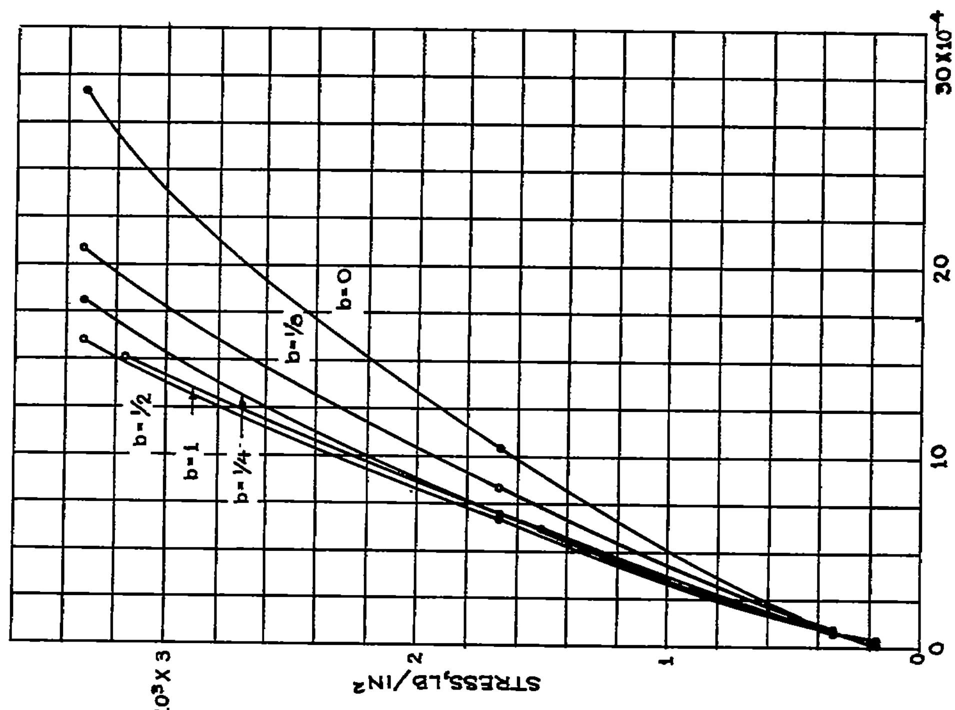


FIG. 17.-SHEAR STRESS vs SHEAR STRAIN SPECIMEN 31 L

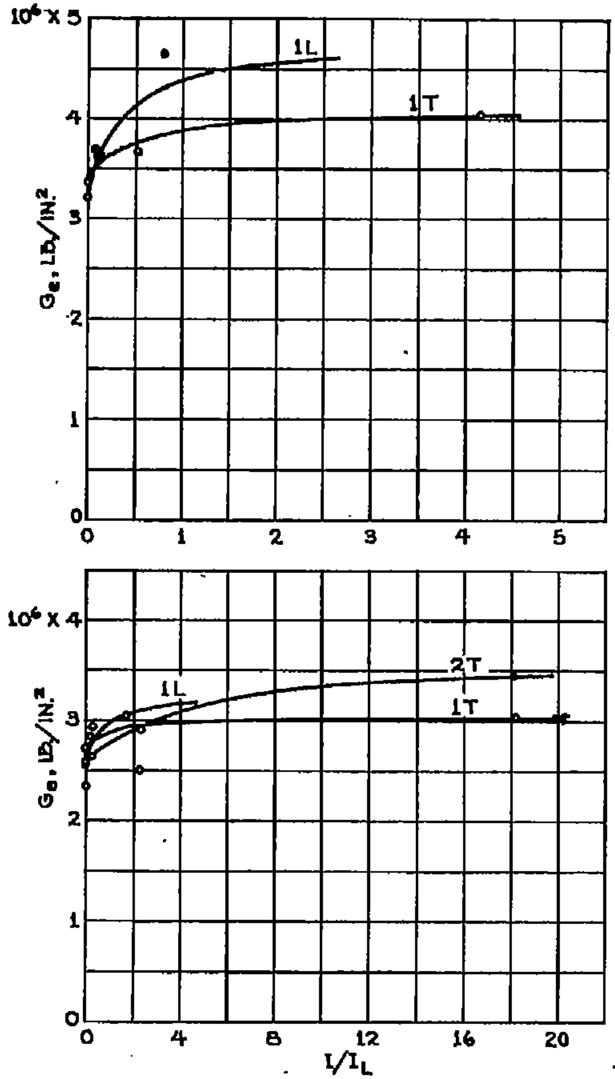


FIG. 19.-VARIATION OF EFFECTIVE SHEAR MODULUS WITH RIB MOMENT OF INERTIA, k=10¼".

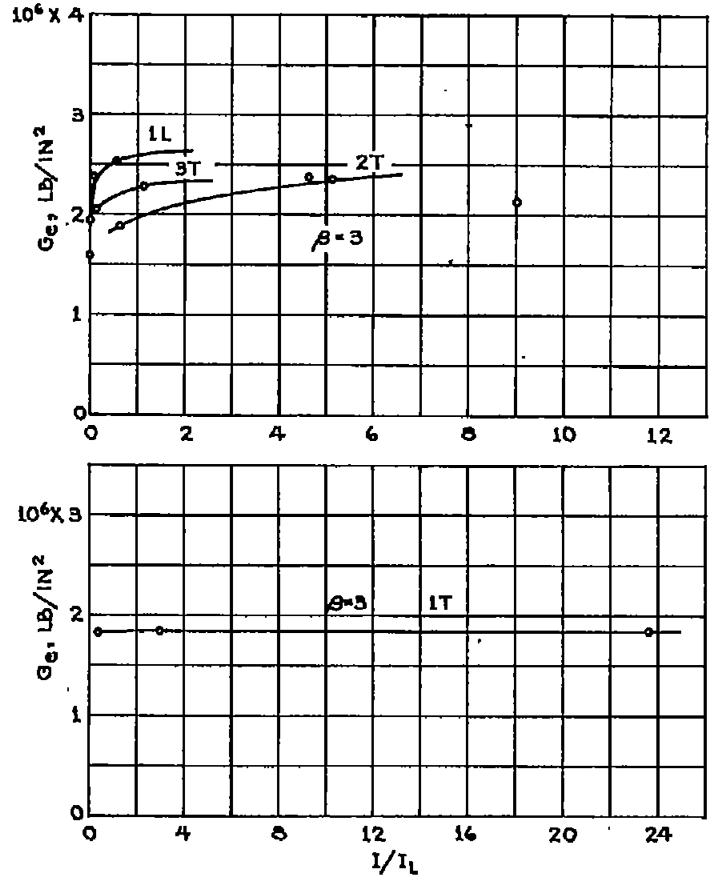


FIG. 20.-VARIATION OF EFFECTIVE SHEAR MODULUS WITH RIB MOMENT OF INERTIA, k=10¼"